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(Unclassified Title)
NEGOTIATED PROPOSAL
FOR IMAGE ANALYSIS

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Proposal No. TO-B 88-66 (Revision 2)
1 June 1967

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NEGOTIATED WORK STATEMENT ON IMAGE ANALYSIS

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- a. mensuration
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NEGOTIATED WORK STATEMENT ON IMAGE ANALYSIS

I. TAKING SYSTEM

1. Evaluation of New System Performance

Reports on the most advanced system will be studied by selected [] personnel. From these reports, live data and specifications will be derived for the new system. These numbers will guide us in our study on this program of exploitation equipment, and of the preparation of duplicates.

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2. Specifications for New System

From the data contained in the reports on the new system, we will determine the performance characteristics that shall be required of exploitation instrumentation. We will determine if the optical specifications of present instrumentation show them to be adequate for the new system. If the new system brings about photographic or optical demands that exceed the present exploitation instrumentation, then new exploitation criteria will be calculated, and it will be determined if equipment meeting the new requirements is available, can be fabricated, or can be made by alteration of existing equipment.

II. EXPLOITATION EQUIPMENT

1. Coherence Evaluation of the Sponsor's Viewers, etc.

During the first phase of this program we have shown the importance of coherence effects in the evaluation and observation of images.

In this proposed second phase of the program, [] will supply the necessary personnel and equipment to determine by direct measurement the coherence of the illumination in light tables, enlargers, microdensitometers, microscopes and other special types of analyzing systems in use at the Sponsor's facility. These measurements will be designed to determine whether coherence problems are likely to arise when this equipment is used with the higher quality imagery obtained from the most advanced system, as determined under Item I. Where feasible, such tests will be conducted by making two pinhole interferometer measurements of the degree of coherence of the light. For small coherence intervals, the coherence will be determined by such techniques as observation of the form of the diffraction patterns from extremely small apertures or comparison of images of certain test objects with images produced by known degrees of coherence.

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2. Feasibility of Laser Viewers

- a) Performance of mechanical and electronic laser beam deflector or flying spot scanners will be evaluated for applicability to image exploitation.
- b) Performance of rear projection laser light viewers will be evaluated with particular emphasis upon coherence effects upon exploitation.

III. PHOTOGRAPHIC CHEMISTRY OF DUPLICATION

The goal of this program is to improve the quality of duplication images for mensuration purposes. This shall be done by studying exposure and processing conditions to give edge enhancement in the duplicate.

1. Exposure and Processing of the ON

ON material will be exposed in our laboratory on 3404 film, to controlled target information of our design, and also to scene information. With the assistance of the [] effort, simulated image exposures will be made on 25X1 a high resolution camera system that shall equal the quality of the most advanced system.

2. Duplication Exposure

Positive duplicates of the prepared ON material will be exposed on 8430, 5427 or other recommended film. Exposures may be made on a Niagara printer. Live ON material may be used for the exposure, as desired by the Sponsor.

3. Processing of Duplicate

Processing of the exposed duplicates will be done under controlled conditions. With the assistance of the [] 25X1 sensitometric spray processor (designed for the processing of duplicates under Air Force contract) will be remodeled for use on this program. New developers and development conditions will be used in processing the duplicate.

4. Support Measurements

Measurements to be made on the duplicate shall include the following:

- a) Microdensitometer traces to determine loss of contrast at high frequency, and to determine maximum edge enhancement.
- b) Electron Microscope observation of the duplicated image. This will allow a determination of the best silver structure and image location for maximum information read-out.

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- c) Granularity measurements as determined under Section V to allow for maximum information read-out.

5. Check with [] Program

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Processed duplicates will be sent to [] so that they may determine the ability of these films to yield mensuration information. Feedback information will allow us to correlate and improve our exposure and processing procedures.

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6. Correlation with the Sponsor

Through personal visits and consultations with the Sponsor in his laboratory, we will attempt to instigate improvements in duplication chemistry.

IV. IMPROVED IMAGE EVALUATION METHODS

1. IDT Evaluation Methods

We propose a series of experimental studies on the application of the [] to the exploitation of information on the duplicate positive in the Sponsor's laboratory. In this work we will develop techniques that will tell us under what circumstances, particularly difficult interpretative information can be derived by this instrument.

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- a) In the normal mode we will determine when the relatively long time scan can yield maximum information.
- b) We will determine when the Gestetner mode, coupled to a suitable enlarger can be used for faster read-out.

2. Improvement of Microscope Equipment by Image Quality Assessment

The assessment of the quality of microscope systems which employ incoherent illumination is based on a knowledge of the system's transfer function. The purpose of this part of the program is to permit judicious selection of commercially available instruments or design and construction of the appropriate instruments which are best suited to measure the transfer functions of the Sponsor's microscope components and systems.

[] will determine:

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- a) the area of applicability of the transfer function analysis with particular reference to the applications of microscope systems in the process of photointerpretation, and
- b) the best method of measuring the optical transfer function from the viewpoint of its further use in quality assessment and the ease with which it can be used in a routine manner by the Sponsor's personnel.

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SECRET**V. GRAIN LIMITED IMAGE STUDY**

Modern photographic science recognizes the "granularity" of the photographic image as a fundamental parameter, analogous to noise in electronic systems. Granularity determines the ultimate detectivity of a film, and is often the limiting factor in the ability of a photographic interpreter to draw information from a film. Unfortunately, granularity varies with density, development conditions, and the aperture of the measuring system.

We will determine by study and experiment the best way to measure granularity for use in evaluating photographic duplicates and for use in preparing image enhancement "filters" or optical procedures that may be used to extract information from photographic noise.

VI. ENGINEERING SUPPORT

The Engineering Department of the Physical Sciences Division of [] will assist the Chemistry and Optics groups during the program outlined above and will perform the following tasks:

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1. Redesign and fabricate one black and white sensitometric spray processor to meet the specifications of the proposed program and to be used in the evaluation of Section III above.
2. Design and fabricate one enlarging printer to be used in the evaluation of Section IV above.
3. Modify one Gestefax facsimile printer (Model No. 451) to be used in the evaluation of Phase IV above.

VII. PUBLICATIONS SUPPORT

During the image evaluation program, the Physical Sciences Division of [] will meet all the reporting requirements which are detailed as follows:

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1. Submit five copies of the Monthly Letter Reports.
2. Submit five copies of the Quarterly Technical Reports.
3. Submit five copies of the Final Technical Report.
4. Interim Report is second quarterly report and should include (as a separate document) proposal for next year's program with cost estimate.

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VIII. []

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The subcontractor, [] shall concentrate its program in two broad areas which represent essentially the continuation of the work started by them during the first phase of this program. These two broad areas are:

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- a) Mensuration
- b) Examination of the effective exposure concept

In addition to these two broad areas, [] will also provide support in other areas as required by the program.

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1. Generation and Analysis of Controlled Samples

This task is essentially a continuation of the effective exposure evaluation. With the experimental setup, carefully controlled functions in exposure can be imaged on film. The present effort has been devoted to only the study of film response to sine waves of a specified spatial frequency. It is also possible to generate functions which are more complicated than this by proper spatial filtering. Since the present program is being used to develop a model of film properties to sine wave stimuli, the model can be tested for more complicated functions by comparing the response predicted, versus the experimental results. This effort will thus be useful for experimental material to use in the verification of the theoretical model. One of the primary lines of investigation will include the use of additive stimuli.

2. Mensuration Techniques

This phase will be devoted to two (2) activities:

- a) Monitoring activity and support to the SPPF measurement program. Data will be reduced and methods developed as required for the effective continuation of that activity. The objectives are:
 - 1) Determine the degree of assistance involved in the use of a density related measurement in the mensuration task.
 - 2) Evaluate quantitatively the error propagation in positive transparency production, from the standpoint of small scale observations.
- b) Extension of the mensuration activity by experimental investigation. One purpose is to determine the nature of images in respect to measurement by providing experimental determination of edge properties as a function of local density level and difference in density across the edge. A by-product of this investigation will be guidelines for best use of microdensitometry as a measurement aid. Similar measurement will be

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accomplished under varying conditions of illumination to determine if repeatability is a function of illumination. Spectrum and degree of coherence will be varied with a limited number of cases used for each condition.

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CHAPTER 2

COHERENCE STUDIES

In the previous phases of this program, extensive studies on the effects of coherence in imaging systems were conducted. These studies included measurements of the intensity distribution in images of various objects for various degrees of coherence of illumination of the object, and measurements of the coherence of the illumination in actual image exploitation instruments. It was found that the presence and extent of coherence effects primarily depend on three factors:

1. Resolution limit of the imaging system
2. Spatial frequency content of the object
3. Spatial coherence of the light illuminating the object.

Other factors such as aberrations in the imaging lens and contrast of the object can also affect the extent to which coherence influences images, but these apply to specific imaging conditions and cannot be included in a general analysis.

CONSTRUCTION AND USE OF NOMOGRAPH

The conditions under which coherence will be a problem in a general imaging system can be found from the nomograph in Figure 1, which was constructed from analysis of the experiments on partially coherent imaging and from coherence measurements. To use this nomograph, first the quantities R and $N.A.$ are determined from the physical characteristics of the system. For the instruments under consideration, these two quantities representing information about the resolution limit and the coherence are easier to determine than other quantities representing the same information. A straight line is then drawn through the R and $N.A.$ columns to intersect the L column, and the spatial frequency for this intersect point is read. For objects containing spatial frequencies less than this intercept frequency, coherence effects will essentially be absent. As the frequency content of the object increases beyond this point, coherence effects will become increasingly prominent. The class of objects for which an instrument can be considered to operate incoherently can thus be determined with this nomograph. Use of the nomograph will become clearer as we consider its application to various instruments.

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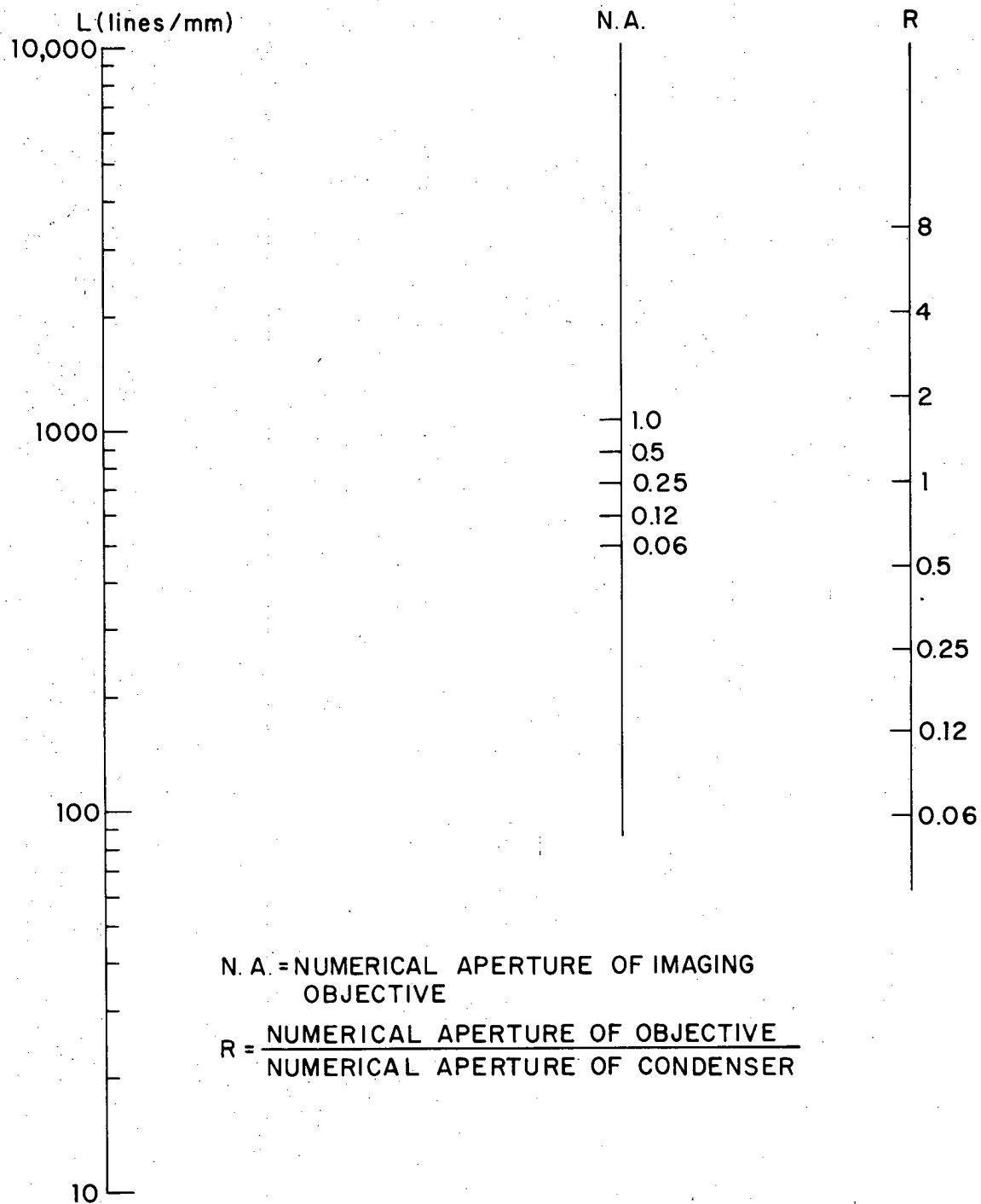


Figure 1. Nomograph for Finding Conditions Under Which Coherence Effects Are Present in an Imaging System

APPLICATION OF NOMOGRAPH TO INSTRUMENTS IN CURRENT USE

Zoom 70 Microscope — This instrument employs light-table illumination for which the numerical aperture is 1.0. The numerical aperture of the imaging optics is approximately 0.05. Thus, R is 0.05 and N.A. is 0.05. As determined from the nomograph, the intercept frequency is about 10,000 ℓ/mm , which is far beyond the resolution limit of this or any other optical microscope. This microscope is therefore incoherent for all objects that can be examined optically.

High-Power Stereoviewer Microscope — This instrument employs condenser illumination; the numerical aperture of the illumination is adjustable from a minimum of 0.02 to a maximum of 0.40. As normally used, the illumination is set for its maximum numerical aperture. The three objectives usually used have numerical apertures of 0.10, 0.20, and 0.25. The intercept frequencies, as determined from the nomograph, are 2100 ℓ/mm , 1600 ℓ/mm , and 1400 ℓ/mm respectively for these three objectives when the condenser is wide open. In viewing photographic material in which the spatial frequencies are limited to values far below these frequencies, there will be no coherence effects. For objects such as resolution targets or biological specimens, coherence effects may be present particularly with the N.A. 0.20 and 0.25 objectives. If the condenser is stopped down to its minimum numerical aperture of 0.02, the intercept frequencies are about 20 ℓ/mm for all three objectives. In this case, the instrument is highly coherent for high-resolution photographic imagery, which means that the Stereoviewer can be used as a coherent spatial filtering system. This is in fact being done in a similar instrument in the grain filtering experiments to be discussed later.

Joyce-Loebl Microdensitometer — This instrument accepts standard microscope objectives for both condenser and objective. It is normally used with a condenser and objective of equal numerical apertures; thus R should always equal 1. A typical N.A. is 0.25. The intercept frequency is then 700 ℓ/mm . This microdensitometer will therefore show coherence effects for a wider class of objects than the Stereoviewer, although it may still be considered to be incoherent when tracing certain photographic records. It should be noted that a photographic object can have associated with it grain frequencies that are higher than those associated with the signal, and if the

scanning slit in the microdensitometer is small enough so that grain noise is prevalent, coherence effects may be present. If, however, the trace is made with a slit that is wide enough to smooth out the grain noise, coherence effects will be absent. This example points out the necessity for looking closely at the nature of the object and the operation of the instrument to determine if coherence effects are present.

Mann Microanalyzer — Since this instrument employs both a condenser and objective of N.A. 0.25, the discussion of the Joyce-Loebl microdensitometer applies here also.

Image Quantizer — This instrument also employs a condenser and objective of N.A. 0.25, and therefore the intercept frequency is also 700 ℓ/mm . This instrument is designed to operate on objects having a maximum frequency of about 5 ℓ/mm , and any higher frequencies will not be resolved by the printout. The Image Quantizer is thus incoherent for the class of objects for which it was designed to be used.

Projection Printer — This instrument contains objectives of numerical apertures 0.08, 0.16, 0.22, and 0.45, and condensers of numerical apertures 0.16, 0.30, and 0.45. Since each objective is supposed to be used in conjunction with the condenser most closely matched in N.A., the resulting values of R are between 0.5 and 1.0. Assuming the condensers and objectives are matched in this way, we find from the nomograph that the intercept frequencies for the four objectives are 800 ℓ/mm , 500 ℓ/mm , 800 ℓ/mm , and 1200 ℓ/mm , in order of increasing numerical aperture. Again, these frequencies are sufficiently high that the signal frequencies in photographic records will not be affected by coherence. Examination of photomicrographs of photographic targets made with this instrument under conditions where individual grains are resolved reveals that the images of the individual grains exhibit coherence effects, which is to be expected because the grains have higher frequencies associated with them than the intercept frequencies. When such a photomicrograph is scanned in the Image Quantizer, however, the optimum scanning aperture smears out the individual grain images, so that coherence will have no effect on the final trace.

This discussion of the individual instruments is summarized in Table 1. We can conclude that no coherence problems exist when these instruments are used for the normal examination of photographic material. This is basically due to the limited

TABLE 1
SUMMARY OF COHERENCE EFFECTS IN INSTRUMENTS CURRENTLY USED

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Instrument	Condenser N. A.	Objective N. A.	Intercept Frequency (ℓ/mm)	Comments
Zoom 70 Microscope	1.0	0.05	10,000	Incoherent under all conditions
High-Power Stereoviewer Microscope	0.40 as normally used. Can be stopped down to as low as 0.02.	0.10 0.20 0.25	2100 1600 1400	Intercept frequencies given assume that condenser N. A. = 0.40. They will decrease as the condenser is stopped down. Can become sufficiently coherent to do coherent spatial filtering if stopped down completely.
Joyce-Loebl Microdensitometer	Interchangeable. Normally equal to that of objective.	Accepts all standard microscope objectives. Typical value is 0.25.	700 for condenser and objective both of N. A. 0.25.	Intercept frequencies can be found from nomograph for other combinations of condenser and objective. Coherence effects may be expected in tracing photographic material if grain is not smoothed out by scanning aperture.
Mann Microanalyzer	0.25	0.25	700	Similar to Joyce-Loebl where coherence effects are concerned.
Image Quantizer	0.25	0.25	700	No coherence effects because resolution is far below intercept frequency.
Projection Printer	0.16 0.30 0.45	0.08 0.16 0.22 0.45	800 500 800 1200	These frequencies assume that objectives are properly matched to condensers. Coherence effects observable in images of grain, but generally averaged out by Image Quantizer scanning aperture.

*The intercept frequency is found from the nomograph in Figure 1. It represents the maximum spatial frequency an object can contain to ensure that coherence effects will not be present in a particular instrument.

spatial frequency content of the information of interest in such material and to the relatively low degree of coherence of the illumination. The coherence effects that may occur are generally associated with the grain noise in the film; such effects are of little importance in situations in which the grain noise is averaged out such as in microscopes where the magnification is insufficient to allow the individual grains to be detected or in scanning instruments where the grain noise is integrated out with a sufficiently large scanning aperture.

In situations in which coherence effects appear to be present, no simplified explanation can be made. The basic difficulty here is that the intensity distribution in the image is no longer linearly related to that of the object. This is not a severe problem when the image is to be observed visually. Where precise measurements of the intensity distribution in an image are required, however, as is often the case in techniques used for instrument evaluation, large errors can result. It is particularly in such cases that the possibility of the presence of coherence effects must be carefully considered.

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